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WIRELESS ENHANCER USING A SWITCH MATRIX

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WIRELESS ENHANCER USING A SWITCH MATRIX

BACKGROUND OF THE INVENTION

[0001] The present disclosure relates generally to communication radio hardware and software, and more particularly, to the repeater or enhancer used in wireless communication systems.

[0002] A repeater or enhancer is a radio apparatus that is used in wireless communication systems to boost or enhance radio signal strength in order to extend the radio coverage. An enhancer typically includes a donor antenna, a service antenna, and an electronic circuit that performs signal reception, amplification, and re-transmission. For the forward link (or down link) communications from a base transceiver station (BTS) to a terminal such as a mobile station, an enhancer receives a signal from the BTS through the donor antenna, enhances and re-transmits the signal to the intended terminals with the service antenna. Similarly for the reverse link (or up link) communications from the terminal to the BTS, the enhancer receives a signal from the terminal through the service antenna, enhances and re-transmits it to the BTS using the donor antenna. As such, the enhancer merely stands in a radio path between the BTS and the terminals, and receives and transmits the radio signals at the same time.

[0003] It is understood that typically the transmitted signal level is much higher than the received signal level. Since the enhancer receives and transmits signals at the same time, an effective isolation mechanism is required between the donor and service antennas. Furthermore, if the BTS and terminals employ time division duplex technology (TDD) for both

the forward and reverse link communications, the enhancer needs to know the exact timing for the TDD switching in order to implement a mechanism to connect the donor antenna to an input port of the corresponding receiver circuit, and similarly, the service antenna to an output port of the transmitter circuit during the forward link communications. Likewise, the TDD switch timing helps to appropriately connect the service antenna to the input port of the receiver circuit and the donor antenna to the output port of the transmitter circuit during the reverse link communications.

[0004] In the conventional art, several methods for improving the isolation mechanism of a enhancer have been proposed. For example, Qi Bi et al (US.Pat.No.5835848) discloses a method using a feedback signal whose amplitude and phase are adjusted in response to the amplitude and phase of a sampled input signal when the normal output of the enhancer is turned off for a short period of time so the sampled input is the leakage signal. The information extracted is then used in the normal operation to cancel out the leakage. This method can be classified as an active noise cancellation method and needs sophisticated hardware and software implemented in the enhancer.

[0005] In another example, Hideto Oura (US.Pat.No.6115369) discloses another method where the transmission and receiver times are allocated at different time slots. This method is classified as a store-then-transmit method. Its drawback is that the enhancer will not be transparent to the BTS and terminals, and the data throughputs between the BTS and terminals are reduced at least by half.

[0006] Stefan Kallander et al (US.Pat.No.5603080) discloses a method where a high radio frequency used between the BTS and enhancer is first converted at a first converter into a low frequency, which is capable to transmit over cable to a second converter where the low frequency signal is converted into the high radio frequency, which is then transmitted to the terminals. This method requires two converters that locate separately and a transmission media between them.

[0007] What is needed is an efficient method for determining the TDD switch timing and an improved method and system that provides more signal isolation between the donor and service antennas to avoid oscillation.

SUMMARY OF THE INVENTION

[0008] This disclosure provides an improved enhancer, which uses a switch matrix to increase the isolation between two antennas. For either a forward or reverse communication, the enhancer has a first antenna for receiving an incoming signal, and a receiver sub-system that amplifies and converts the incoming signal from the first antenna to a first predetermined frequency band. The enhancer further has a demodulator coupled to the receiver sub-system for demodulating the converted signal, and detecting timing information thereof. Also contained in the enhancer is a transmitter sub-system operable with the receiver sub-system that converts the signal from the receiver sub-system to a second predetermined frequency band and further amplifies the signal. After the signal is thus enhanced, a second antenna is used for further transmitting the amplified signal from the transmitted sub-system. The switch matrix controls connection switching among the first antenna, the second antenna, the transmitter sub-system, and the receiver sub-system based on the timing information detected by the demodulator and based on whether the incoming signal comes from a terminal or a base transceiver station (BTS).

[0009] In another example of the present disclosure, the switch matrix is further enhanced by including four controlled amplifiers to attenuate signal leakage from the switches of the switch matrix. The controlled amplifier can be a low noise amplifier, a power amplifier, or even a double pole single throw switch.

[0010] In another example of the present disclosure, a synthesizer is used to produce local oscillator frequencies for use by the receiver sub-system and the transmitter sub-system. The synthesizer can also be enhanced by including several pairs of switches and amplifiers arranged in such a way to further isolate local oscillator frequencies generated by the synthesizer.

[0011] One example of the enhancer disclosed is an enhancer using time division duplex technology, and contains a donor antenna and a service antenna. The donor antenna is designed to be a patch antenna facing the BTS direction, while the service antenna can be a dipole antenna lying on the same plane as the patch antenna. Both the patch and dipole antennas have a null point in their radiation patterns along the vertical direction so that such an arrangement will maximize their mutual isolation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Fig. 1 illustrates a schematic of an enhancer according to one example of the present disclosure.

[0013] Fig. 2 illustrates a variation of the enhancer of Fig. 1 incorporating band pass filters in the switch matrix thereof according to one example of the present disclosure.

[0014] Fig. 3 illustrates another variation of the enhancer of Fig. 1 incorporating controlled amplifications in the switch matrix thereof according to one example of the present disclosure.

[0015] Fig. 4 illustrates another variation of the enhancer of Fig. 1 incorporating controlled amplifications and additional switches in the switch matrix thereof according to one example of the present disclosure.

[0016] Fig. 5 illustrates another variation of the enhancer of Fig. 1 incorporating controlled amplifications and additional switches in the switch matrix thereof according to another example of the present disclosure.

[0017] Fig. 6 illustrates another variation of the enhancer of Fig. 1 incorporating additional controlled switches in the switch matrix thereof according to one example of the present disclosure

[0018] Fig. 7 illustrates a physical layout design of a donor antenna and service antenna according to one example of the present disclosure.

[0019] Fig. 8 illustrates a mechanism for assigning two locally generated frequencies for two mixers of the enhancer of Fig. 1 according to one example of the present disclosure.

[0020] Fig. 9 illustrates a enhancer implemented with a modulator sub-system according to another example of the present disclosure.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0021] Fig. 1 illustrates a schematic of an enhancer 10 according to one example of the present disclosure. The components of the enhancer includes a donor antenna 12, a service

antenna 14, a switch matrix 16, a receiver sub-system 18, a transmitter sub-system 20, a demodulator sub-system 21 which contains a demodulator 22, an analog-to-digital converter (ADC) 24, and a base band module (DSP) 26, and a synthesizer sub-system 28. The switch matrix 16 is controlled by switch signals that are derived from the TDD switch timing information provided by the DSP 26. Essentially, the switch matrix 16 makes appropriate connection arrangements for forward and reverse link communications to "switch in" corresponding either the donor antenna or the service antenna on one hand, and the receiver sub-system or the transmitter sub-system on the other hand. For example, Table 1 illustrates the expected connections for the input port A for the receiver sub-system 18 and the output port B for the transmitter sub-system 20.

Switch port connection		
	Forward link	Reverse link
Receiver input port A	Donor Antenna	Service Antenna
Transmitter output port B	Service Antenna	Donor Antenna

Table 1

[0022] Taking a forward link communication session as an example, when the enhancer powers up, the switch matrix 16 connects the donor antenna 12 to the receiver input port (e.g., port A) by default. It is understood that control mechanisms may be implemented to sweep only a carrier frequency band of the entire operating spectrum of the receiver subsystem at a time in order to "lock in" an incoming signal at its best receiving condition. One or more criteria can be set up to decide which carrier frequency band should be selected, and such criteria may include the considerations for the strength of the signal, the signal-to-noise ratio after demodulation by the demodulator sub-system 21, and the traffic loading of the carrier frequency band. When such a carrier frequency band is determined, the donor antenna 12 is tuned to receive the incoming signal at this carrier frequency band. When the receiver sub-system 18 receives the incoming signal from the donor antenna 12, the signal goes through a first band pass filter 30 to eliminate other signals that are not in a desired frequency band. The survived signal is further amplified by a low-noise amplifier (LNA) 32 and down converted to an intermediate frequency (IF) through a mixer 34, which provides a locally generated frequency such as LO1 or LO2. The signal is then further filtered by a second filter 36 (e.g., another band pass filter), and further amplified to a desired level by a second amplifier 38

operating at the intermediate frequency (e.g., an adjustable gain amplifier (AGC1)) such that the signal level falls into an acceptable operation range of the demodulator 22 and the ADC 24. It is further understood that the incoming signal is continuously monitored by base band module 26, and if the quality of the received incoming signal is not satisfactory (e.g., the signal-to-noise ratio drops below a threshold value), the enhancer scans another carrier frequency band in order to use a new carrier frequency.

[0023] On the transmitter sub-system side, connecting from the output of the AGC1, the signal is first amplified through another adjustable gain amplifier 40 (e.g., AGC2), and up-converted into a radio frequency through another mixer 42 using a locally generated frequency such as the local oscillator frequency LO1 or LO2. Thereafter, the signal is further amplified through a power amplifier (PA) 44 and another band pass filter 46, and eventually sent out to the predetermined terminal through the service antenna. As such, the radio signal from the BTS has been boosted through the enhancer 10, and further sent to the terminal. The synthesizer module 28 provides all the local oscillator frequencies (IF, LO1 and LO2) needed for the demodulation and signal conversions (e.g., up/down conversions). With the procedure similar to selecting the best receive carrier frequency between BTS and enhancer, the receiver sub-system 18 also continuously scans or sweeps a carrier frequency band of the operating spectrum thereof to find an "ideal" frequency band for transmitting outgoing signals. One consideration for determining such an ideal frequency band is the noise level of such a frequency band. Another consideration is to keep the separation between the carrier frequency band used by the receiver sub-system 18 and the carrier frequency band used by the transmitter sub-system 20 for transmission as far apart as possible. As such, the incoming and outgoing signals are isolated to the maximum, thereby reducing signal oscillation therebetween.

[0024] The demodulator sub-system 21 plays a role in determining switching timing information between the reverse link and forward link communication sessions. The demodulator 22 demodulates the IF signal from the output of the receiver sub-system into an analog base band signal, and the ADC 24 further converts the analogue base band signal into a digital signal. The base band module 26 performs a synchronization function, and determines the TDD switch timing information from the digital signal. A searching algorithm is employed in the DSP to search and obtain the TDD switch timing information. The search algorithm may

vary depending on communication protocols used with the particular wireless system in which the enhancer is integrated therein. For example, if the protocol used has a dedicated synchronization channel, the starting timing of the TDD forward link can be determined by searching correlation peak with the dedicated synchronization channel. After the synchronization is achieved, the TDD switch timing information can be obtained by demodulating the information contained in the synchronization channel. For example, if the total TDD time frame is fixed, the synchronization channel can contain the information indicating the ratio between the forward and reverse links, from which the starting timing for the reverse link is then derived.

[0025] The dedicated synchronization channel can be a virtual channel that may be mapped into a variety of physical channels so long as the mapping mechanism is predefined in the protocol and known to the enhancer. For example, the synchronization channel can be a short period of data burst transmitted before every TDD frame, or one of the co-channels that is transmitted with other traffic channels.

[0026] In addition, the BTS carrier frequency can be obtained at the same time during the synchronization. This is done by sweeping the relevant frequency spectrum, and at each frequency point, the base band module searches the correlation peak. It is understood that a correlation peak exists only when the enhancer is tuned to the correct BTS carrier frequency.

[0027] With the TDD switch timing information on hand, the switch matrix is fully controlled wherein, during the forward link, the donor antenna is connected to the receiver input port (port A in Fig. 1) and service antenna is connected to the transmitter output port (port B in Fig. 1). On the other hand, during the reverse link, the donor antenna is connected to the transmitter output port and the service antenna is connected to the receiver input port.

[0028] As shown in Fig. 1, two mixers/local oscillators (LOs), LO1 and LO2, may be used in the enhancer. This also provides a frequency different from the BTS carrier frequency for the communication link between the enhancer and the terminal.

[0029] One benefit of using a different frequency is that the isolation between the enhancer's donor and service antennas can be further improved. For example, if the BTS carrier

frequency is f1, one can use f2 (wherein f2 differs from f1) for the link between the enhancer and terminals provided there is sufficient separation between f1 and f2.

[0030] This concept of separating the frequency bands to isolate signals feeding into the donor and service antennas can be further improved by incorporating filters with the switch matrix 16. Fig. 2 is the switch matrix integrated with two band pass filters according to another example of the present disclosure. For example, a first band pass filter 50 can be implemented with the service antenna 14 so that signals on f1 can pass while signals on f2 are to be rejected. Similarly, a second band pass filter 52 can be added to screen the signals before they reach the donor antenna 12 so that f2 signals will pass but f1 signals will be blocked. Therefore, during a forward link communication, there are few f2 signals feeding back into the donor antenna 12, while on the reverse link, there are few f1 signals feeding back into the service antenna 14.

[0031] Another benefit of using different frequencies at the donor and service antenna is that, as mentioned above, the enhancer can scan the available operating spectrum and determine which frequency band corresponds to a minimum interference, and then use that particular frequency for the link between the enhancer and the terminals/BTSs to ensure signal quality and to reduce interference.

[0032] Referring back to Fig. 1, in order to select appropriate frequencies for the mixers 34 and 42, and after f2 is determined, LO1 and LO2 are given as follows in one example of the present disclosure:

$$LO1 = f1 - IF;$$
$$LO2 = f2 - IF$$

and the assignment of LO1 and LO2 to the mixer 34 and mixer 42 has to ensure that for either the forward link or reverse link communications, the two mixers are using different LOs. Table 2 below illustrates such a mutual exclusivity in assigning the LOs.

LO1 and LO2 selection table		
	Forward link	Reverse link
Mixer1	LO2	LO1
Mixer2	LO1	LO2

Table 2

[0033] Referring to Fig. 3 where controlled amplifications are added in the switch matrix to reduce the coupling between antennas through the switch matrix itself. Low noise amplifiers 60 and 62 are added in the receiver paths from antennas to port A (switch 65), and power amplifiers 64 and 66 are added in the transmitter paths from port B (switch 68) to antennas. The gains of the amplifiers are controlled by the base band module through, for instance, their power down pins (PD). During the forward link period, LNA1 60 and PA2 64 will be activated while LNA2 62 and PA1 66 will be de-activated (powered down). So, any leakage from switch 68 will be further attenuated by the de-activated PA1 66, while any leakage from switch 70 will be further attenuated by the de-activated LNA2 62. Similarly, during the reverse link period, LNA2 62 and PA1 66 will be activated while LNA1 60 and PA2 64 will be de-activated (powered down). So, any leakage from switch 68 will be further attenuated by the de-activated PA2 64, while any leakage from switch 69 will be further attenuated by the de-activated LNA1 60. The improvement for the isolation of the switch matrix is equal to the gain difference between the active and de-active amplifiers.

[0034] Referring to Fig. 4 where the LNA1 60 and LNA2 62 of Fig. 3 are replaced by controlled switch 72 and switch 74. During the forward link period, switch 72 will be on and PA2 64 will be activated while switch 74 is off and PA1 66 will be de-activated (powered down). So, any leakage from switch 68 will be further attenuated by the de-activated PA1 66, while any leakage from switch 70 will be further attenuated by the turned-off switch 74. Similarly, during the reverse link period, switch 74 is turned on and PA1 66 will be activated while switch 72 is turned off and PA2 64 will be de-activated (powered down). Any leakage from switch 68 will be further attenuated by the de-activated PA2 64, while any leakage from switch 69 will be further attenuated by the turned-off switch 72. The improvement for the isolation of the switch matrix is equal to the gain difference between active amplifier PA and turned-off switch.

[0035] Referring to Fig. 5, PA1 64 and PA2 66 in Fig. 3 can be replaced with controlled switch 76 and switch 78. The isolation of the switch matrix is then improved by the gain difference between the active amplifier LNA and the turned-off switch.

[0036] Referring to Fig. 6, another embodiment of Fig. 3 is to replace all amplifiers with controlled switches. During the forward link period, switch 80 and switch 82 will be on while switch 84 and switch 86 will be off. During the reverse link period, switch 84 and switch 86 are

turned on while switch 80 and switch 82 are turned off. The isolation of the switch matrix is thus improved by using the additional controlled switches.

[0037] Appropriate physical design and construction of the donor antenna and service antenna can also maximize antenna isolation, thereby improving the reception to both the BTS and terminals.

[0038] The local oscillator frequencies for mixer1 and mixer2 can be selected differently for forward and reverse links as indicated in Table 2. Fig. 7 illustrates a mechanism for feeding appropriate locally generated frequencies to the mixers through a switch matrix 90 with controlled gain amplifiers. The switch matrix 90 has four switches 92, 94, 96 and 98, and four amplifiers A1 through A4. During the forward link, the switch matrix 90 is configured that LO2 and connected to mixer1 34 and LO1 is connected to mixer2 42. The amplifiers A2 and A3 are activated while amplifiers A1 and A4 are de-activated (powered down). During the reverse link, the switch matrix is configured that LO1 and connected to mixer1 34 and LO2 is connected to mixer2 42. The amplifiers A1 and A4 are activated while amplifiers A2 and A3 are de-activated (powered down). As such, the LO in the desired switch paths are amplified by the active amplifiers and the leakages in un-desired switch path are attenuated by the de-activated amplifiers. The isolation between LO1 and LO2 is improved by the same amount as the gain difference between active and de-active amplifiers.

[0039] Fig. 8 illustrates an enhancer 100 implemented with an improved modulator sub-system 102 according to another example of the present disclosure. This enhancer 100 is almost the same as the enhancer 10 (Fig. 1) except for an expanded modulator sub-system 102. The expanded modulator sub-system 102 is similar to the modulator sub-system 21 of Fig. 1 except it has added several additional components to be integrated into the enhancer 100 for injecting information from the enhancer into the signal path and further sending same out to the BTs and terminals. The additional components of the expanded modulator sub-system 102 includes a modulator 104 and a switch 106 between the receiver and transmitter sub-systems, and a digital-to-analog converter 108. In summary, whenever the enhancer 100 needs to send information to the BTS or terminals, the switch 106 connects the modulator to the transmitter sub-system. As such, the information generated in the based band module 26 will be sent out from the modulator 104 to the transmitter sub-system. The information that the enhancer sends

out can be any of the following: the forward or reverse signal quality indication, interference level, hardware status or alarm, power down or frequency change request, or acknowledge to messages that are sent from BTS or terminals to the enhancer.

[0040] Fig. 9 illustrates a design of the donor antenna and service antenna according to one example of the present disclosure. Assuming the enhancer 10 is hanging on a wall or post 110, the donor antenna 12 is designed to be a patch antenna facing the BTS direction, while the service antenna 14 can be a dipole antenna lying on the same plane as the patch antenna. Both the patch and dipole antennas have a null point in their radiation patterns along the vertical direction so that such an arrangement as shown in Fig. 3 will maximize their mutual isolation.

[0041] The above disclosure provides several different embodiments, or examples, for implementing different features of the disclosure. Also, specific examples of components, and processes are described to help clarify the disclosure. These are, of course, merely examples and are not intended to limit the disclosure from that described in the claims.

[0042] While the disclosure has been particularly shown and described with reference to the preferred embodiment thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the disclosure.